R&MPR
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Reliability & Maintainability Predictions Report (R&MPR) for the ISS Human Research Facility (HRF) Refrigerated Centrifuge (RC)

Life Sciences

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RELIABILITY & MAINTAINABILITY PREDICTIONS REPORT (R&MPR)

FOR

HUMAN RESEARCH FACILITY (HRF)

REFRIGERATED CENTRIFUGE

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ACRONYMS

A/D	Analog/Digital
AM	Activity Monitor
COTS	Commercial Off The Shelf
DC	Duty Cycle
F/R	Failure Rate
FGI	Foot Ground Interface
HRD	Hardware Requirements Document
HRF	Human Research Facility
ISS	International Space Station
IVA	Intravehicular Activity
JSC	Johnson Space Center
LLIL	Limited Life Items List
LMSO	Lockheed Martin Space Operations
MA/YR	Maintenance Actions per Year
MMCH/Y	Mean Maintenance Crew Hours per Year
MTBF	Mean Time Between Failure
MTBMA	Mean Time Between Maintenance Actions
MTTR	Mean Time To Repair
PC	Portable Computer
PCMCIA	Personal Computer Memory Card Industry Association
PCS	Portable Computer System
PO	Pulse Oximeter
RC	Refrigerated Centrifuge
R&MPR	Reliability & Maintainability Predictions Report
RBD	Reliability Block Diagram
ROMS	Range Of Motion Suit
SLAMMD	Space Linear Mass Measurement Device
WS	Workstation

DEFINITION OF TERMS

1) Operating Failure Rate (F/R_{op}) - The Operating Failure Rate is an established rate of random failure of part or component.

2) Non-operating Failure Rate (F/R_{non-op}) - The Non-operating Failure Rate is defined as the percentage of Operating Failure Rate which varies with the type of component being analyzed (mechanical components are 0%, electromechanical components are 5%, and electronic components are 10%).

3) Mean Time Between Failure (MTBF) - The estimated average time in hours between failures due to random effects under nominal operating conditions at the maintainable equipment level. MTBF is defined as the reciprocal of the F/R (thus $MTBF_{op} = 1 / F/R_{op}$ and $MTBF_{non-op} = 1 / F/R_{non-op}$).

4) Duty Cycle (DC) - Percent of time an equipment is operating.

5) Ratio (R) - Ratio of Op. MTBF to Non-Operating MTBF or $MTBF_{op} / MTBF_{non-op}$.

6) Operating Ratio (OP) - Defined as the difference between the sum of the Ratio and Duty Cycle and the product of the Ration and Duty Cycle or (R + DC) - (R x DC).

7) Adjusted Mean Time Between Failure ($MTBF_{adj}$) - Defined as the ratio of Operating Mean Time Between Failure to the Operating Ratio or $MTBF_{op}$ / OP.

8) Life Characteristic (L-Char) - Equals the required operational life requirement set by ISS program (currently 10 years).

9) K-Factor (K) - Equals a certain set value for different types of parts or components (electronic components is 1.31 and mechanical components is 1.35)

10) Random Mean Time Between Maintenance Actions ($MTBMA_{rand}$) - Defined as the inverse of the sum of the inverse of the Adjusted Mean Time Between Failure and the ratio of the K-Factor & Adjusted Mean Time Between Failure or $1 / (1 / MTBF_{adj} + K / MTBF_{adj})$.

11) Corrective Maintenance Actions per Year (MA/YR_{cm}) - Defined as hours per year (8760 hrs) times the number of components being analyzed divided by the Random Mean Time Between Maintenance Actions or 8760 x Quantity / $MTBMA_{rand}$.

12) Mean Time To Repair (MTTR) - The estimated time it takes to remove and replace a failed component in the system being analyzed.

13) Mean Maintenance Crew Hours per Year (MMCH/Y) - Defined as the following:
MA/YR_{cm} x # of crew required for maintenance x MTTR.

1.0 INTRODUCTION

This report contains the Reliability & Maintainability Predictions Report (R&MPR) for International Space Station (ISS) Human Research Facility (HRF) Refrigerated Centrifuge (RC).

2.0 PURPOSE

The purpose of this R&MPR is to calculate the following terms to in order to establish the Mean Maintenance Crew Hours per Year (MMCH/Y) for the HRF RC: $F/R_{non\text{-}op}$, $MTBF_{op}$, $MTBF_{non\text{-}op}$, R, OP, $MTBF_{adj}$, $MTBMA_{rand}$, and MA/YR_{cm}. This R&MPR also identifies life limited items that will be documented in the Limited Life Items List (LLIL) Report for the HRF RC (ref. LMSEAT 33210).

3.0 SCOPE

This report provides the R&MPR for the ISS Human Research Facility (HRF) RC. The R&MPR determines the average time the HRF RC and its components will last and how long it will take the Intravehicular Activity (IVA) crew to perform corrective and preventive maintenance tasks. The R&MPR involves the development of a Reliability Block Diagrams (RBDs), which, like functional block diagrams, illustrate the HRF RC system in terms of interconnecting blocks with each block showing component name and HRF Rack location number.

4.0 GROUND RULES

1.) Mean Time Between Failure (MTBF) and failure rate data has been supplied by Commercial Off The Shelf (COTS) vendors and by similarity to items listed in the Lockheed Martin Failure Rate document LMSC-D520737D.

2.) Duty Cycle (DC) assumptions:

a) DC based on the amount of use in a 1-year period.

b) 30 minutes for calibration, operation & data downlink. (1/2 Hr. total)

c) 4.5 Hours per week will be performed per crew member.

d) 1 crew members (maximum) will take part in RC activities.

e) The RC DC will be the following HRF equipment operation time for a single run:

1) HRF Refrigerated Centrifuge (RC)

$$DC = \frac{\text{5.0 hours/week x 1 crew/run x 52 weeks/year}}{\text{(8,760 Hr./1 year period)}} = 0.02976$$

DC for the RC (DC calculation above) x 100% = <u>2.976 %</u>

5.0 REFERENCE DOCUMENTS

LS-71026, Reliability Plan for the Human Research Facility (HRF)

LS-71013, Logistics and Maintenance Plan for HRF

JSC-16043E, JSC Reliability and Maintainability Plan for Life Sciences Project Division

LMSEAT 33210, Limited Life Items List (LLIL) for the ISS Human Research Facility (HRF) Refrigerated Centrifuge (RC)

LMSEAT 33208, Failure Modes & Effects Analysis/Critical Items List (FMEA/CIL) Report for the ISS Human Research Facility (HRF) Refrigerated Centrifuge (RC)

6.0 SYSTEM DESCRIPTION

The Human Research Facility (HRF) Refrigerated Centrifuge (RC) will be used to separate substances of different densities. A common centrifuge is a container that spins rapidly. Centrifuges may be used to quickly separate substances that would normally separate slowly under the influence of gravity. The HRF Refrigerated Centrifuge is intended to provide a system of separation of biological samples based on differing sample densities. The refrigerated centrifuge will be capable of separating blood into its components and separating saliva from saturated dental cotton rolls.

6.1 PARAMETER INPUTS

The HRF Refrigerated Centrifuge has a programmable centrifugal force of 1000 to 14,000 RPMs at increments of 100 RPMs. The RC is capable of running from 1 to 30 minutes, set in 1 minute increments. The Refrigerated Centrifuge contains a liquid-crystal display (LCD) to display the following fields: temperature, RCF, RPM, and time. To enter the experiment parameters (temperature, time, spin speed, and braking speed) the crew will use a push-button control panel on the front of the unit. It also has six (6) LEDs for the controls and status fields which include a stopped position, RCF selector, unbalanced rotor, spinning rotor and unlocked lid.

6.2 REFRIGERATION PROCESS

The RC will also provide refrigeration at +4 °C to all samples. The refrigeration method utilized by the centrifuge is the vapor compression cycle. Vapor compression systems consist of four components: a compressor, a condenser, an evaporator, and an expansion device.

The compressor takes low pressure, low temperature refrigerant gas and compresses it to high pressure, high temperature gas. Reciprocating pistons intake vapor at a low pressure, and compress the vapor before sending it to the discharge line. The cool, low pressure gas entering the compressor is referred to as suction gas. The high pressure, high temperature gas exiting the compressor is called discharge gas. The existing compressor relies on oil sumping at the bottom of the compressor to lubricate the gears and therefore is gravity dependent. From the compressor, the hot, high, pressure gas travels through the discharge line in the condenser. The condenser is the part of the system where the heat is rejected by condensation. In the vapor compression system, as the hot gas travels through the condenser, it is cooled by the air passing over it. As the hot gas refrigerant cools, drops of liquid refrigerant from within the coil.

Eventually, when the gas reaches the end of the condenser, it has condensed completely; that is, only liquid refrigerant is present. In order for the condenser to function correctly, the fluid passing through the fins of the condenser (usually air), must be cooler than the working fluid of the system (Freon).

The purpose of the expansion device in a vapor-compression refrigeration cycle is to control flow of refrigerant to the evaporator. As the refrigerant leaves the condenser, it has cooled and condensed to liquid but still under high pressure. In order for the liquid to absorb the necessary heat in the evaporator, its pressure must be reduced, which is accomplished within the expansion device. The RC uses a capillary tube to accomplish this pressure reduction.

The evaporator is the component of the cycle which actually absorbs the heat from the conditioned space. The evaporator is similar in construction to the condenser, but its function is opposite. As the fluid leaves the expansion device, it is a cool liquid. As it passes through the evaporator, it picks up heat from the room, and evaporates into a gaseous form. This evaporation is what enables the refrigerant to absorb the heat energy from the room.

As the refrigerant leaves the evaporator, it is returned to the cooled, low pressure state, and is sent back to the compressor to being the cycle again. Under normal circumstances the refrigerant will not wear out; it will be reused again and again, changing its physical form, but not its chemical composition. The refrigerant is the fluid present in the vapor-compression refrigeration cycle used to absorb heat in the evaporator and release heat in the condenser. The RC uses R404a as it working fluid. R404a is environmentally friendly and has been given a toxicity of 0 and safe to use.

7.0 CONCLUSION

The HRF RC Failure Rate Summary Table (see Appendix A) revealed no individual limited life items (no individual HRF-supplied hardware item for the RC had an adjusted Mean Time Between Failure (MTBF) value of less than 87,600 hours (10 years)).

The Mean Maintenance Crew Hours per Year (MMCH/Y) (See Appendix B) for the HRF supplied RC equipment was 0.12467. It will be up to the HRF R&M Customer to determine if this MMCH/Y value is reasonable.

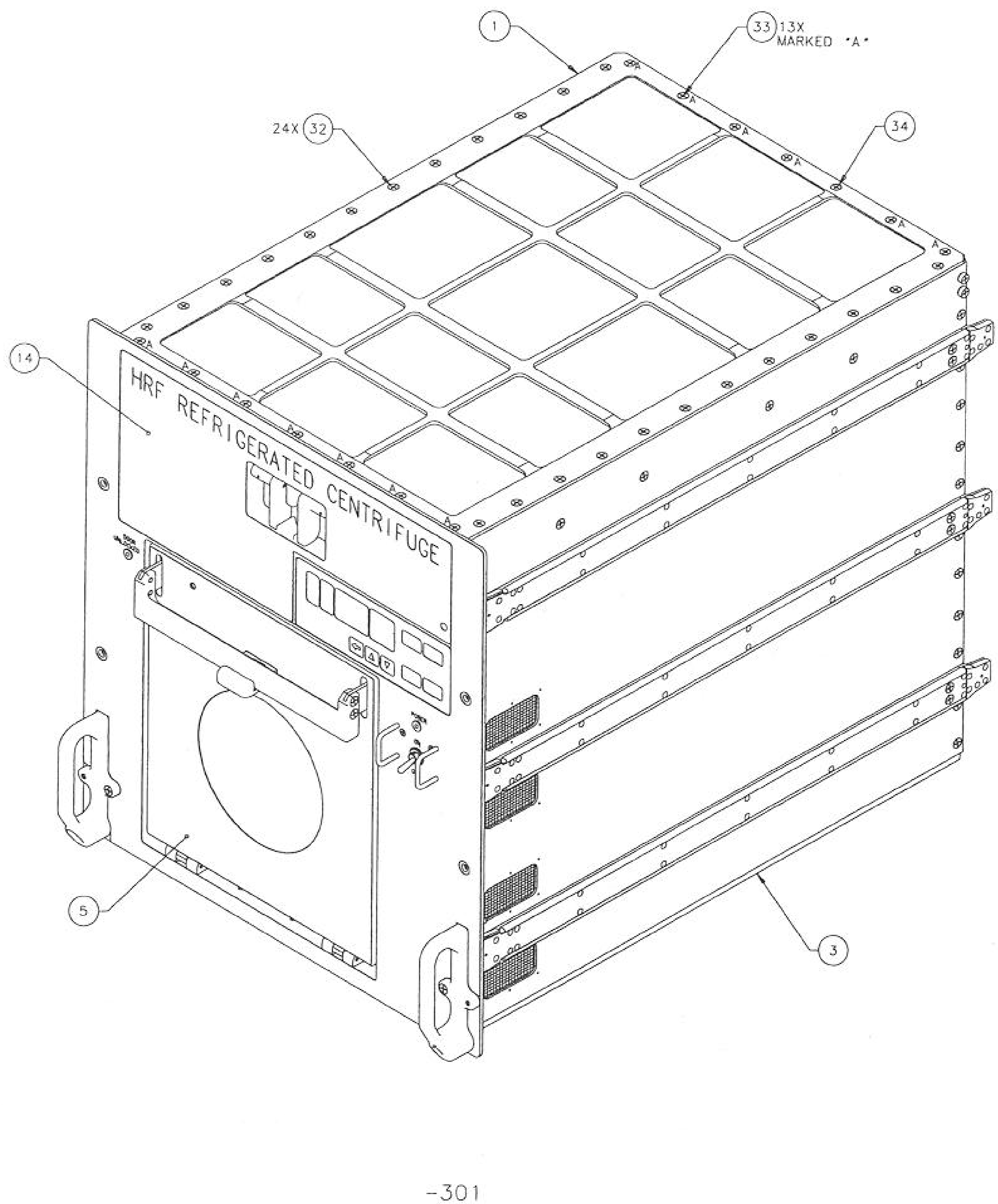

Figure 3-1 HRF Refrigerated Centrifuge

Appendix A

HRF RC Failure Rate Summary

Where:

Operating Failure Rate (F/R_{op}) - The Operating Failure Rate is an established rate of random failure of part or component.

Non-operating Failure Rate ($F/R_{non\text{-}op}$) - The Non-operating Failure Rate is defined as the percentage of Operating Failure Rate which varies with the type of component being analyzed (mechanical components are 0%, electromechanical components are 5%, and electronic components are 10%).

Mean Time Between Failure (MTBF) - The estimated average time in hours between failures due to random effects under nominal operating conditions at the maintainable equipment level. MTBF is defined as the reciprocal of the F/R (thus $MTBF_{op} = 1 / F/R_{op}$ and $MTBF_{non\text{-}op} = 1 / F/R_{non\text{-}op}$).

Duty Cycle (DC) - Percent of time an equipment is operating. For the HRF RC, the DC is assumed to be 0.028% based on the assumptions stated in the Ground Rules section of this report (see page 5, Section 4.0).

HRF RC Failure Rate Summary Table

Appendix B

Mean Maintenance Crew Hours per Year (MMCH/Y) Summary

Where:

Operating Mean Time Between Failure ($MTBF_{op}$) - The Operating Mean Time Between Failure for the HRF RC is equivalent to the Adjusted MTBF found on page 12 of the HRF RC Failure Rate Summary Table divided by the assumed duty cycle (0.694%, see Ground Rules on how this was derived).

Non-operating Mean Time Between Failure ($MTBF_{non-op}$) - The Non-operating Mean Time Between Failure for the RC is assumed at 1E+20 hours.

Operating to Non-operating MTBF Ratio (R) - R is equivalent to the ratio of the $MTBF_{op}$ to $MTBF_{non-op}$.

Duty Cycle (DC) - Percent of time an equipment is operating. For the HRF RC, the DC is assumed to be 0.694% (see Ground Rules on derivation).

Life Characteristic (L-Char) - Equals the required operational life requirement set by ISS program (currently 10 years).

K-Factor (K) - Equals a certain set value of 1.31 for the ADAS (as it is mainly composed of electronic components).

Random Mean Time Between Maintenance Actions ($MTBMA_{rand}$) - Defined as the inverse of the sum of the inverse of the Adjusted Mean Time Between Failure and ratio of the K-Factor and Adjusted Mean Time Between Failure or $1 / (1 / MTBF_{adj} + K / MTBF_{adj})$.

Corrective Maintenance Actions per Year (MA/YR_{cm}) - Defined as hours per year (8760 hrs) times number of components being analyzed divide by the Random Mean Time Between Maintenance Actions or $8760 \times Quantity / MTBMA_{rand}$.

Mean Time To Repair (MTTR) - The estimated time it takes to remove and replace a failed component (assumed to be one half hour for RC or 0.5 hours).

Mean Maintenance Crew Hours per Year (MMCH/Y) - Defined as the following = MA/YR_{cm} x # of crew required for maintenance x MTTR.

HRF RC MMCH/Y Summary Table

HRF Cellular Biotechnology Cryodewar	
REFERENCE DESIGNATOR	1.0
ORU	Cellular Biotechnology Cryodewar
QTY	1.0
OP (HOT) MTBF	7,235
NONOP (COLD) MTBF	180121
(R)	0.04017
DUTY CYCLE	0.43840
OPERATION RATIO (OP)	0.460959399
ADJUSTED MTBF	471,385
LIFE LIMIT (L- CHAR)	10
ADJUSTED MTTF	79942.03859
K-FACTOR	1.16
RANDOM MTBMA	242550.17585
TOTAL CM MTBMA	73525.24656
MA / YR (CM)	0.11914
NO. of PM R & R PER YR	0
MTBPM R&R	0
MA / YR (PM R&R)	0
NO. of PM INSP/SERV PER YR	520
MTBPM INSPECT / SERVICE	16.84615385
MA / YR (PM INSP / SERV)	520
MTTR (CM)	0.16816
MTTR (PM R&R)	0
MTTR (PM INSP / SERV)	0.000081344
CREW # FOR MAINT. ACTION	2
MMCH / Y (CM)	0.04007
MMCH / Y (PM R&R)	0
MMCH / Y (PM INSP / SERV)	0.08459776
TOTAL PRED. MMCH / Y	***0.12467***

APPENDIX C

Reliability Block Diagrams (RBD's)

1.0 Refrigerated Centrifuge

- FR= 1.1 Drawer Assembly
- FR= 1.2 Door Assembly
- FR= 1.3 Power Unit Assembly
- FR= 1.4 Filter/Dryer Assembly
- FR= 1.5 Power Supply (PSCM)
- FR= 1.6 Centrifuge Assembly
- FR= 1.7 Centrifuge Motor Support Assembly
- FR= 1.8 Door Interlock Switch Assembly
- FR= 1.9 Door Latch Assembly
- FR= 1.10 Lock Slider Assembly
- FR= 1.11 Stowage Drawer Assembly
- FR= 112 Control Panel
- FR= 1.13 Control PWB Assembly
- FR= 1.14 Power Cable Assembly
- FR= 1.15 Control Cable Assembly
- FR= 1.16 Data Cable Assembly
- FR= 1.17 Braking Resistor
- FR= 1.18 Ribbon Cable Assembly
- FR= 1.19 LED (Red and Green)
- FR= 1.20 Circuit Breaker 3 Pole
- FR= 1.21 Power Connector
- FR= 1.22 Data Connector
- FR= 1.23 EMI Filter
- FR= 1.24 Resistor
- FR= 1.25 Seal, Door
- FR= 1.26 PWB Assembly, Fan Control

1.1 Drawer Assembly

FR=
1.1.1 Slide Assembly

FR=
1.1.2 Retention Latch Assembly

FR=
1.1.3 Common Fan and Door Assembly

1.1.4 Common Fan and Door Assembly

FR=
1.1.4.1 Hinge Assembly

FR=
1.1.4.2 Fan Assembly, Common

1.2 Door Assembly

FR=
1.2.1 Hinge Assembly

FR=
1.2.2 Door Latch Pawl (RH and LH)

FR=
1.2.3 Door Stop Assembly

1.3 Power Unit Assembly

FR=
1.3.1 Compressor Assembly

FR=
1.3.2 Condenser Assembly

1.3.2 Condenser Assembly

FR=
1.3.1 Condenser

FR=
1.3.2 Fan (on mount)

1.5 Power Supply Control Module

FR=
1.5.1 Current Limiter

FR=
1.5.2 8 FET Power Board

FR=
1.5.3 DC/DC Converter – Control Board

1.6 Centrifuge Assembly

- 1.6.1 Power Supply PWB — FR=
- 1.6.2 Door Latch Pawl (RH and LH) — FR=
- 1.6.3 Frequency Controller PWB — FR=
- 1.6.4 Seal, Front Panel — FR=
- 1.6.5 Temperature Sensor — FR=
- 1.6.6 Speed Sensor — FR=

1.7 Centrifuge Motor Support Assembly

- 1.7.1 Motor — FR=
- 1.7.2 Imbalance Switch — FR=

1.11 Stowage Drawer Assembly

- 1.11.1 Latch Assembly — FR=
- 1.11.2 Lock Assembly — FR=